YES/NO DISCRIMINATION WITH SPATIO-TEMPORAL CHARACTERISTICS OF EEG

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Abstract-**Yes/No discrimination using spatio-temporal characteristics of EEG is investigated. For the correlation between EEG signals, we introduce two new representations useful in time domain calculation, synchronization rate and polarity. Using synchronization rate, average polarity, polarity fluctuation, and normalized cross-correlation, we study possibility of Yes/No discrimination with linear decision function. Overall, normalized cross-correlation exhibits the best results and the others also show affirmative prospects.**

Keywords **- Yes/No discrimination, EEG, spatio-temporal, linear decision function, synchronization rate, polarity, cross correlation**

I. INTRODUCTION

To catch what people think is one of the fascinating dreams but has been thought to be impossible. However, recently, there have been some studies about the achievement of the dream by the name of BCI (Brain Computer Interface) [1-11], one of the new prospective methods in the field of the human computer communications.

There are two approaches in the BCI study, intentional EEG generation and direct recognition. In the former approach, the intentional EEG generation, a subject is asked to perform a special action that is supposed to be done for a special task, for example, imagination of movement [2-6]. And for practical use, training of both the subject and the computer systems is usually required to a certain extent. The direct recognition is, as what it means literally, to read the subject's mind without any trick.

As you guess, the more promising and realistic one is the former, BCI by the intentional EEG generation and so far most BCI studies have been in this category. The latter one, the direct EEG recognition seems very difficult to achieve, and sometimes it seems even impossible. However, it is really close to the essence of mind reading concept and if it succeed, it will give a great influence on human life.

The major concern of this work is Yes/No discrimination, one of the elementary human decisions. This work is a kind of preliminary study of the direct EEG recognition. The purpose is to investigate the possibility of the direct EEG recognition.

In this paper, we have a special focus on the spatio-temporal characteristics of the brain activity during the decision-making event, especially Yes/No decision. We hope that there is a certain brain activation that corresponds to a special task. If it exists, we would like to find out the sequences and utilized those characteristics for BCI.

Analyses of EEG data in frequency domain have been prevalent. But, in this study, we consider processes in time domain. For sure, analyses in time domain are merits and demerits compared with those in frequency domain. We expect that the methods in time domain have several advantages, especially for study of spatio-temporal characteristics.

For the quantification of spatio-temporal characteristics, we introduce two new representations that can be calculated in time domain. With the two new representations and the other established ones, we investigate the possibility of the Yes/No discrimination.

II. EXPERIMENTS

The Yes/No decision experiment has three types of Yes/No questions. The first type questions are to confirm if the spellings of two meaningless series of alphabets (Korean) are exactly the same. The second type concerns the similarities of two pairs of words (For example, note : pencil = blackboard : chalk). And the third type concerns the continuation of the rules lying in a series of drawings.

In the experiments, the subject was supposed to continue pressing the ready button when a question appeared on the monitor screen and until the subject made a decision. Just after the decision-making, the subject was asked to release the ready button and push the Yes or No button (both with right hand) as quickly as possible. The moment the subject release the ready button is called RT (Reaction Time) and the time duration from RT to the Yes/No button press is called MT (Movement Time). In this study, RT is more important and we will consider RT only.

Nine healthy right-hand subjects took part in the experiments voluntarily. Total number of questions were 12, 4 questions per each type. EEG signals were recorded at Fp_1, Fp_2, O_1, and O_2 with one ground electrode on forehead and the linked-ears reference. The sampling frequency was 128Hz. We used 0.1-30Hz band pass filter. In this study, the EEG signals recorded at Fp_1 and Fp_2 are of special interest.

III. SPATIO-TEMPORAL VARIABLES

Cross-correlation is the popular representation for the spatio-temporal characteristics. In this study, we introduce two new concepts additionally, synchronization rate and polarity. The new variables may represent the correlation between two signals.

Synchronization rate means how much two signals vary together. In other words, synchronization rate is the ratio of the time length where the two signals vary in phase to the total time length. Mathematically, synchronization rate $SR(t)$ is defined as follows:

$$SR(t) = \int_{t-w}^{t} H\left(\frac{ds_1(t')}{dt'}\frac{ds_2(t')}{dt'}\right)dt', \quad (1)$$

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Abstract

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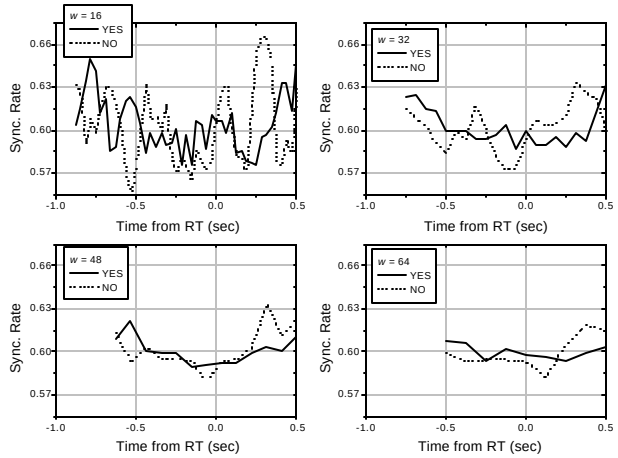

Fig. 1. Average variations of synchronization rate near RT. The solid lines are for Yes decision and the dotted for No decision.

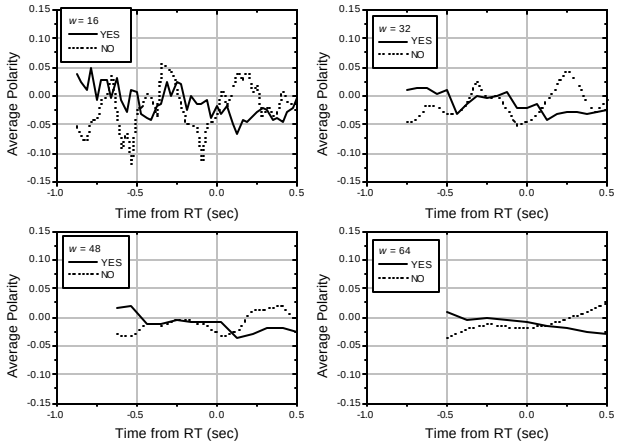

Fig. 2. Average variations of average polarity near RT. The solid lines are for Yes decision and the dotted for No decision.

where, s_1 and s_2 are the signals. The calculation window is (t-w, t) where w is the size of calculation window. And $H(x)$ is the step function that returns 1 for positive x and returns 0 otherwise. Note that synchronization rate is modified cross-correlation of time derivatives of signals.

Polarity is related to the rotational direction in the two-dimensional phase space that consists of two signals, for example, where the abscissa is s_1 and the ordinate is s_2. Polarity also implies which signal precedes the other. The definition is as follows:

$$p(t) = \frac{d\vec{s} \cdot \hat{\boldsymbol{q}}}{|\, d\vec{s} \cdot \hat{\boldsymbol{q}}\,|}, \qquad (2)$$

where, $d\vec{s}$ is a two dimensional vector that consists of the time derivatives of the two signals, (ds_1/dt, ds_2/dt) and $\hat{\boldsymbol{q}}$ is the unit vector in the azimuthal direction. As you see, polarity is related to the angle between $d\vec{s}$ and $\hat{\boldsymbol{q}}$. Note that synchronization rate is a kind of amplitude whereas polarity is a kind of phase of the correlation between two signals.

In this paper, we consider the average and standard deviation of polarity in a calculation window. Since the standard deviation of polarity can represent the amount of polarity fluctuations, we will call the standard deviation of polarity "polarity fluctuation" for convenience.

IV. Results and Discussions

The variables we consider in this study are synchronization rate, average polarity, polarity fluctuation, and normalized cross-correlation with zero time delay. Normalized cross-correlation is calculated by dividing the cross-correlation by square root of auto-correlations of two signals.

All the variables are calculated for each Yes/No question at every moment with moving calculation window. We averaged the values calculated at the same time to RT, which is a similar procedure to obtaining ERP by averaging EEG. While averaging, we removed the time intervals where EEG signals are contaminated by artifacts such as eye blinks. The total number of valid Yes/No decisions is 84, 57 for Yes and 27 for No decision.

The average variations of synchronization rate with respect to time are shown in Fig. 1. The solid lines are for Yes decision and the dotted lines for No decision. The sizes of calculation windows are 16, 32, 48, and 64 data points, respectively. Remind that the sampling rate is 128Hz. The overlap is 75% the calculation window.

In Fig. 1, we can find differences between variations of the synchronization rate for Yes and No decisions. Some of these differences are found to be statistically meaningful (For example, the synchronization rate near RT-0.5s when w=16). This implies a possibility of Yes/No discrimination with synchronization rate. The differences of synchronization rate between Yes and No decision are prominent for w=16 and for the range (RT-1s, RT-0.5s).

The average variations of the average polarity are shown in Fig. 2. There are also differences between Yes and No decision, especially for w=16 and for (RT-1s, RT-0.5s). This may support the Yes/No discrimination with average polarity.

Fig. 3 shows the average variations of the polarity fluctuation. The Yes/No differences can also be seen in the figure. Unlike those of synchronization rate and average polarity, the differences are more distinct for w=32 or w=48.

The average variations of the normalized cross-correlation are shown in Fig. 4. The Yes/No differences can be seen for the range (RT-0.7s, RT-0.2s) unlike those of the other variables.

In all figures, there are some differences for Yes and No decision even though it is not clear how large they are. All the results show possibilities of Yes/No discrimination with those variables. Details can be found elsewhere [12].

It is important to investigate the efficiencies of the use of the variables for Yes/No discrimination. For the efficiency estimation, quantification of the possibility of Yes/No discrimination is required. For the purpose, we adopt linear decision function.

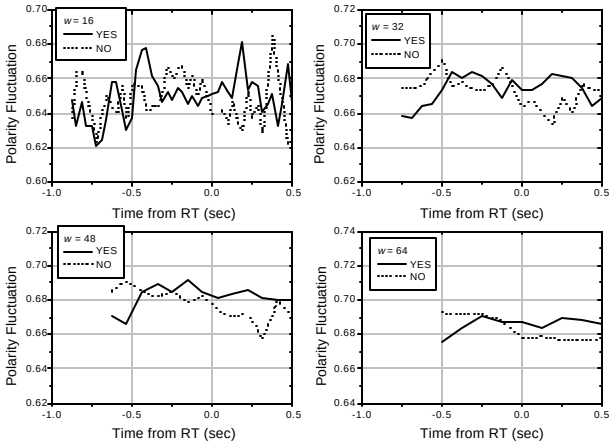

Fig. 3. Average variations of polarity fluctuation near RT. The solid lines are for Yes decision and the dotted for No decision.

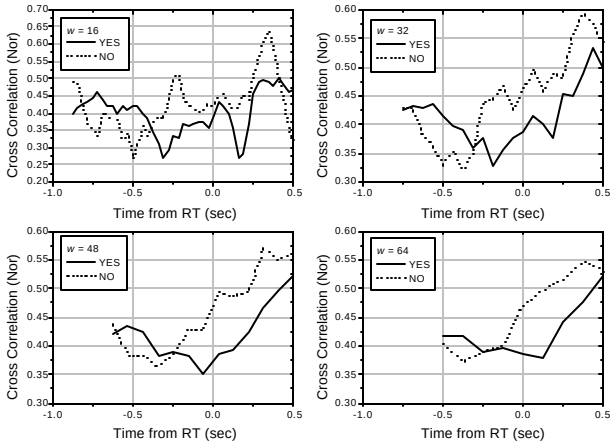

Fig. 4. Average variations of normalized cross-correlation with zero time delay near RT. The solid lines are for Yes decision and the dotted for No decision.

The linear decision function is a kind of black box that has features as input and returns the answers as output. The linear decision function can be written as follows:

$$y = a_0 + a_1 x_1 + a_2 x_2 + \ldots + a_n x_n. \quad (3)$$

Here, $\{x_i\}$ is the input feature set and $\{a_i\}$ is the coefficient set that should be optimized. And y is the output. In this case, the input features can be a series of, for example, synchronization rate and the output is Yes or No.

As the input features, we used a series of synchronization rate, average polarity, polarity fluctuation, and normalized cross-correlation with different parameters (calculation window size and overlap). The range of feature extraction is (RT-1s, RT). We optimized the coefficients of the linear decision function with least square method. For the coefficient optimization, all data without artifact contamination are used. With the optimized coefficients, Yes/No discriminations are performed for the data used for the coefficient optimization.

Usually, for training of classifiers and evaluation of the performance, a different data set is used. However, even with this weak performance test, the purpose of this study, the investigation of possibility of Yes/No discrimination, can be fulfilled.

The success rates of Yes/No discrimination are shown in Table I for several calculation parameters. The total discrimination rate is the ratio of number of success to total number of valid Yes/No decisions. Remind that the numbers of Yes or No decisions are different. The average discrimination rate is the average of the discrimination rates for Yes and No decisions.

In the table, the discrimination rates for better parameters are 80% or a little bit more, which is not so promising result but it shows a possibility in Yes/No discrimination. We can also find that there is a trend of increasing discrimination rate with increasing number of input features. However, it seems that the calculation window size is more important than the number of input features. For example, let's see the discrimination rate by the polarity fluctuation. Overall, the normalized cross-correlation with zero time delay exhibits the best discrimination rate.

V. Summary and Future Studies

We investigated the possibility of Yes/No discrimination with spatio-temporal variables, synchronization rate, average polarity, polarity fluctuation, and normalized cross-correlation. In conclusion, all the results show possibility of Yes/No discrimination. Especially, the normalized cross-correlation with zero time delay exhibits the best result overall.

TABLE I. SUCCESS RATES OF YES/NO DISCRIMINATION WITH LINEAR DECISION FUNCTION.

Parameters			Synchronization Rate				Average Polarity				Polarity Fluctuation				Normalized Cross-Correlation			
window size	overlap	number of features	Yes	No	Total	Ave	Yes	No	Total	Ave	Yes	No	Total	Ave	Yes	No	Total	Ave
16	12	29	77%	78%	77%	78%	84%	78%	82%	81%	82%	63%	76%	73%	86%	85%	86%	86%
32	24	13	81%	48%	70%	65%	72%	63%	69%	68%	75%	70%	74%	73%	81%	63%	75%	72%
32	28	25	72%	67%	70%	70%	79%	78%	79%	79%	86%	78%	83%	82%	81%	85%	82%	83%
48	36	7	70%	48%	63%	59%	75%	52%	68%	64%	74%	52%	67%	63%	81%	30%	64%	56%
48	44	21	74%	56%	68%	65%	84%	74%	81%	79%	82%	78%	81%	80%	82%	63%	76%	73%
64	48	5	75%	44%	65%	60%	81%	56%	73%	69%	68%	48%	62%	58%	75%	44%	65%	60%
64	60	17	74%	59%	69%	67%	81%	70%	77%	76%	72%	67%	70%	70%	81%	63%	75%	72%

The Yes/No decision making experiment consisted of three different types of questions. The differences among those types should not be underestimated, especially type I, II *vs*. type III. The differences should be studied carefully.

Since calculations in time domain usually have artifact problem, artifact-filtering techniques must be included for practical use. Movement related potentials included in the EEG signal during the Yes/No decision experiment should also be investigated. And optimal feature selection may be one of the future studies.

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